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ABSTRACT

A research project sponsored by the Illinois State Library had two goals: to develop a set of mathematical models suitable for predicting the impact of alternative library network policies on network preformance, and to demonstrate through series of case studies that the methodology developed could feasibly be applied to real library networking problems. Initial research entailed formulating an understanding of the Illinois Library and Information Network and defining operating policies and network performance. Incorporated in an interactive policy analysis program, the model developed was applied to analyzing resource allocation within individual libraries. Three case studies conducted on the interlibrary loan and reference services of three library systems yielded recommendations and request routing suggestions for each. In addition to development and application of the model, three other efforts were pursued: (1) designing a model-based, integrated online management information system, (2) assessing the impact of automated circulation systems on network operations, and (3) studying reimbursement for services. It was felt that the methodology's versatility was illustrated, and that the feasibility of incorporating the model-based approach into an online management information system was demonstrated. A bibliography lists sources in which the topics discussed in the report are considered at length. (FM)

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A MATHEMATICAL MODEL OF THE ILLINOIS INTERLIBRARY LOAN NETWORK

Final Report

Submitted to

Illinois State Library

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INTRODUCTION

This is the eleventh and final report of a five-year (1974-79) research project whose goal was the development of computer-based aids for management decision making in library networks. More specifically, the goal was to develop a set of mathematical models suitable for predicting the impact of alternative network operating policies on network performance. Operating policies were considered to include request routing and document delivery policies as well as alternative implementations of computer and communications technology. Network performance was defined as including: 1) probability of satisfying a request for network services, 2) average waiting time from request initiation until receipt of the desired service, 3) average cost of satisfying a request for services, and 4) average request processing load at each resource library within the network.

Another goal of this research project was to demonstrate, through a series of case studies, that the methodology developed could feasibily be applied to real library networking problems. To this end, three rather extensive case studies were performed. These studies not only demonstrated the usefulness of the methods, but also served to motivate very significant extensions of the methodology, the need for which was not readily apparent before realistic applications were attempted.

In this final report, we will briefly summarize the accomplishments over the course of this project. Every topic discussed in this report is considered at much greater length in

the numerous reports and journal articles produced as the work progressed and listed in the bibliography at the end of this report. In addition, a forthcoming book by the authors, The Control of Library Networks: Mathematical Analysis and Implications for Policy (John Wiley, to appear in 1979), integrates most of the work summarized here, as well as that of other researchers, into a coherent perspective.

INITIAL RESEARCH

The first year of the project was devoted to developing a good working knowledge of library networking and a detailed understanding of the Illinois Library and Information Network (ILLINET). This included an extensive review of the literature as well as development of flow charts depicting the operations of ILLINET at various levels (i.e.,local, regional, and statewide). These efforts resulted in the generation of a set of issues which seemed appropriate to investigate using the proposed methodology.

Early work also included the formulation of definitions of operating policies and network performance as well as the development of an initial library network model. This model was applied within a preliminary case study using data supplied by the Illinois State Library. Because the data had not been specifically collected for the purpose of model-based analyses, the results of the policy analyses were only tentative. However, they were indicative of the type of results to be expected using the methodology which was being developed.

DEVELOPMENT OF THE METHODOLOGY

The methodological work within this project centered around the development of a general method of representing and analyzing library networks. Using a graph theoretic form of representation and a queueing network approach to analysis, a very general model was developed. This model was incorporated in an interactive policy analysis program and later, a model-based management information system. Since interactive policy analysis was deemed to be very important, fully 90% of the program was devoted to interactive features, with the remainder of the program devoted to computation.

It was soon realized that statistical issues were to be a very important aspect of the work. Since a great deal of data was necessary for estimating the model's parameters, an efficient method of data collection and analysis was desirable. This led to the development of procedures for determining how uncertainties, due to small sample sizes, propagated through the library network model and, in that way, led to uncertainties in the model's predictions. This methodology was used repeatedly throughout the case studies to determine data collection needs.

Two other statistical issues were also resolved. A simple method for determining the appropriate length of the data collection period was developed. Further, alternative approaches for forecasting future values of model parameters (particularly demands for services) were investigated. A fading-memory, linear regression method was found most suitable. With the ability to

forecast parameters, it was then possible to avoid having to empirically measure parameters so often.

Considerable effort was also devoted to the development of methods for investigating the impact of alternative computer and communications technologies on network performance. A method was developed, and later integrated into the overall model, that enabled assessment of the impact of location and availability information such as provided by shared-cataloging networks, automated circulation systems, etc. This method was used within the case studies to determine the effects of location and availability information on network performance.

As somewhat of a tangent, the library network model was applied to analyzing resource allocation within individual libraries. Emphasis was on determining how various floor plans would affect waiting time and congestion of patrons as they circulated through the library. The basic premise underlying this application of the library network model was that each function within a library and its associated floor space could be viewed as analagous to a resource library within a network of libraries. Perhaps the most important conclusion to be drawn from this study is the wide range of applicability of the methodology developed in this project.

CASE STUDIES

As briefly noted earlier, in the second year (1975) of the project, a small case study was performed, using a sample of data obtained from the Illinois State Library. The size of this sample was too small to produce any definitive recommendations. Nevertheless, this study served to illustrate the type of information which model-based policy analyses could provide and thereby, motivated further support for the project. Subsequently, in each of the next three years (1976, 1977, and 1978), a case study was performed. These case studies included collecting data for approximately 21,500 unique requests which involved 31,200 network transactions and yielded approximately 600,000 pieces of raw data. Within this section, these studies will be reviewed. However, before the findings of these case studies are discussed, the interlibrary loan operations and the overall structure of the Illinois Library and Information Network (ILLINET) will briefly be described.

The particular problem area that was addressed concerned interlibrary loan and reference services. When a library patron finds that the local library does not own a particular item, it is usually possible to borrow the requested item through interlibrary loan agreements with other libraries, namely the National Interlibrary Loan Code of 1968. Traditionally this approach to interlibrary loan has worked well, particularly when the level of demand was relatively low. However, as networks experience increased demand and, as the number of possible

resource libraries to contact increases, the individual librarian is faced with the difficult task of trying to predict the best route with respect to turnaround time, probability of satisfaction, and cost, if reimbursement is an additional factor.

The Illinois State Library manages a formal statewide interlibrary loan network which serves approximately 1200 libraries and processes over a million requests per year. There are four levels in the network: local libraries, Cooperative Library Systems, Research and Reference Center Libraries, and Special Resource Centers. In general, requests for unowned items at the local library level travel up the hierarchy seeking satisfaction. Communication at the top levels of the network is distributed in the sense that Research and Reference Center Libraries can decide which resource library will be next in the route for unsatisfied requests. Some System level libraries also practice this type of communication, particularly if they have automated circulation control systems which can be accessed remotely.

The main goal of each System library is to satisfy requests with items found in the combined collections of its member libraries. The star structure is represented at the local library level with each System library operating as the control point for processing all requests generated by the member libraries. While local libraries do not have much choice in determining which System to send their requests to, System libraries have considerable freedom in deciding which Research

and Reference Center library should be accessed, as well as specifying the order of the libraries in the route.

With the advent of computer technology, especially as applied to circulation control systems, the librarian can identify resource libraries which not only own the requested item but also libraries which will satisfy the request because the item is known to be on the shelf. This can have a significant impact on library network performance and, as noted earlier, the policy analysis model developed in this project can be used to assess the effects of such computer technology. From this perspective, it is interesting to note that the three case studies reported here represent investigations of library networks with various levels of automation, ranging from Rolling Prairie Library System which was a mostly manual operation, at the time of the case study, to Suburban Library System which employs a high degree of automation. From a modeling perspective, these differences presented an interesting challenge in terms of successfully representing three fairly different networks with a single modeling methodology.

Rolling Prairie Library System

Rolling Prairie (RPL) is one of eighteen regional networks (Cooperative Library Systems) within ILLINET. The headquarters of RPL is in Decatur, Illinois. At the time of this study (1975), RPL served 86 libraries in a 12 county area which, for the most part, could be characterized as rural and suburban.

Twelve weeks of data were collected, starting with those requests initially received by RPL on June 14, 1976 and ending September 5, 1976. Naturally, the data collection period extended beyond September 5th to enable us to obtain all requests received by RPL in the period of interest. Sample size was 3,366 requests, 10% percent of the interlibrary loan workload for RPL during those weeks.

Analysis of this data and subsequent policy analyses led to three general recommendations as well as specific request routing suggestions. The general recommendations were:

1. RPL was attempting to satisfy all requests using their own collection rather than routing the request to member libraries. To this end, RPL would hold a request for an item they owned for a maximum of one month in hopes that the item would be returned. This policy was resulting in a 533% increase in average waiting time for those requests satisfied by RPL. It was recommended that the holding period be reduced to one week.

2. RPL was attempting to maintain control of their requests by having them returned to RPL after each resource library had attempted to satisfy them rather than having them sent automatically to the next resource library in the route. This policy was resulting in a 48% increase in average waiting time.

It was recommended that this policy be abandoned.

3. NPL was tending to ignore state-wide resources until late in the route and instead attempting to satisfy the request in their own region. It was recommended that this policy be somewhat altered.

Illinois Library and Information Network

The focus of this case study was the levels of the network including the Center Libraries and the Special Resource Centers. Four weeks of data were collected, including 100 percent of the requests sent to the Research and Reference Center Libraries and the Special Resource Centers during the month of April 1977. Since some requests stayed in the network for quite some time, the last completed requests were not received until July 1977. The data base resulting from this effort included 11,583 unique requests and, due to routing of requests to multiple resource libraries, data for 16,609 transactions.

Based on this data, policy analyses were performed which led to specific routing suggestions as well as the following general recommendations:

1. ILLINET was using a rather inflexible routing policy in that some resource libraries were almost always queried, regardless of the class of the request. Because one resource library had a relatively low probability of success and another resource library had a relatively high average processing time for

unsatisfied requests, it was recommended that a more flexible policy be employed.

2. ILLINET was using a routing policy that potentially allowed each request to be processed by the same number of resource libraries, regardless of the class of the request. Within a few classes, this was particularly unproductive. Thus, it was recommended that requests in some classes should have relatively short routes. It was predicted that implementation of this recommendation, as well as recommendation 1, would improve probability of satisfaction by 11% with no increases in average waiting time or costs.

3. ILLINET has been continually considering use of various technologies for providing information about the location and availability of desired network services. Based on the reimbursement structure used by ILLINET at the time of this study, it was recommended that ILLINET only consider alternatives that could provide complete location and availability information at a cost of $1.98 or less for four resource libraries.

Suburban Library System

Suburban (SLS) is one of the eighteen regional networks within ILLINET. The headquarters of SLS is in the Chicago suburb of Burr Ridge, Illinois. At the time of this study (1973), SLS served 132 member libraries in an area which, for the most part,

could be described as urban and suburban.

Four weeks of data were collected, including almost 100 percent of the interlibrary loan requests sent to SLS during March 1978. Data for the last completed requests were received in late October. The resulting data base included complete information on the processing of 6567 requests.

Policy analyses performed based on this data provided specific routing suggestions as well as the following general recommendations:

1. SLS was attempting to satisfy all requests using their own collection rather than routing the request to member libraries. Thus, they would often reserve an item that they owned but was currently circulating. Further, they would sometimes purchase a requested item if it was something that they thought would benefit their collection. Unfortunately, the average time for reserves and purchases was quite high. It was recommended that SLS change this practice and instead, use reserves and purchases as a last resort, after other network members had been queried. It was predicted that this change would result in a 31% reduction in average waiting time.

2. SLS was, for the most part, only routing requests to libraries that owned the desired item. Because owned items were not always available, this policy resulted

in some processing of unsatisfied requests. It was recommended that SLS employ their computerized circulation network to determine availability information and thereby assure that requests would only be routed to resource libraries that would satisfy them. This, of course, assumes that complete location and availability information for all resource libraries is employed in routing decisions. It was predicted that this policy would decrease average waiting time by 12% and also, decrease request processing loads at member libraries by 24%.

3. SLS was attempting to maintain control of their requests by having them returned to SLS after each library had attempted to satisfy them rather than having them sent automatically to the next library in the route. It was recommended that automatic referral be considered and predicted that this would improve average waiting time by 5%.

OTHER EFFORTS

Besides the development of the library network model and its application within three case studies, several other efforts were pursued within this project. Most extensive of these was the design of a model-based online management information system which integrated data collection, data entry, report generation, and model-based policy analyses into an overall system. A prototype of this system was developed and used in the process of

performing the last two of the case studies.

Another effort was devoted to assessing the impact on network operations of the CLSI automated circulation systems. Field observations and a questionnaire were used to develop a somewhat informal picture of how CLSI was affecting services as well as record keeping within ILLINET. The most consistently found conclusion was that CLSI reduced the number of network transactions generated by each request (i.e., fewer libraries handled each request).

Finally, the controversial topic of reimbursement for services was studied to an extent. Alternative theoretical approaches were investigated and a questionnaire was used to assess attitudes about reimbursement throughout the State. The overwhelming conclusion was that reimbursement was so highly controversial that rational analysis would provide few benefits.

CONCLUSIONS

The goals of this research project have been quite satisfactorily achieved. A very general and complete methodology was developed and successfully applied within three extensive case studies. Further, by directly applying the methodology to the very different problem of analyzing the usage of floor space within an individual library, the great versatility of the methodology was illustrated. Finally, the feasibility of incorporating the model-based approach into an online management information system was demonstrated. Thus, at this point in

time, the authors are confident that the methodology is ready for general use as an aid to management decision making in library networks.

PUBLICATIONS

Book

1. W. B. Rouse and S. H. Rouse, The Control of Library Networks: Mathematical Analysis and Implications for Policy. New York: John Wiley, to appear in 1979.

Papers

2. S. H. Rouse, A Selected Review of the Literature on Interlibrary Loan Networks. Network, Vol. 2, No. 1, January 1975, pp. 17-25.

3. W. B. Rouse, "A Library Network Model", Journal of the American Society for Information Science, Vol. 27, No. 2, March-April 1976, pp. 88-99.

4. W. B. Rouse, "Performance Criteria for Library Networks: Theoretical Basis and Realistic Perspectives", in A. Kent and T. Galvin, Eds., Library Resource Sharing, New York: Marcel-Dekker, 1977, Chapter 21.

5. W. B. Rouse and S. H. Rouse, "Assessing the Impact of Computer Technology on the Performance of Interlibrary Loan Networks", Journal of the American Society for Information Science, Vol. 28, No. 2, March 1977, pp. 79-88.

6. W. B. Rouse, S. H. Rouse, and M. P. Slate, "Applications of a Library Network Model: Two Case Studies Within the Illinois Library and Information Network", Illinois Libraries, Vol. 60, No. 5, May 1978, pp. 454-458.

7. W. B. Rouse and S. H. Rouse, "The Effect of Parameter Uncertainties on the Predictions of a Library Network Model", Journal of the American Society for Information Science, Vol. 29, No. 4, July 1978, pp. 180-186.

8. S. H. Rouse and W. B. Rouse, "Design of a Model-Based Online Management Information System for Interlibrary Loan Networks", Information Processing and Management, Vol. 15, No. 2, March 1979, pp. 109-122.

9. J. M. Smith and W. B. Rouse, "Application of Queueing Network Models to Optimization of Resource Allocation Within Libraries", Journal of the American Society for Information Science, Vol. 30, No. 4, July 1979.

10. W. B. Rouse and S. H. Rouse, "A Model-Based Approach to Policy Analyses in Library Networks", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-9, No. 9, September 1979.

11. S. H. Rouse and W. B. Rouse, "Analysis of Monograph Obsolescence at Two Levels of an Interlibrary Loan Network", Information Processing and Management, to appear.

12. W. B. Rouse and S. H. Rouse, "Analysis of Library Networks," Collection Management, to appear.

Reports

13. W. B. Rouse, J. L. Divilbiss, and S. H. Rouse, A Mathematical Model of the Illinois Interlibrary Loan Network: Project Report No. 1, Coordinated Science Laboratory Report No. T-14, University of Illinois at Urbana-Champaign, November 1974, ERIC No. ED 101 667.

Includes a review of the literature on interlibrary loan networks, a flow chart description of the Illinois network, a review of methodologies appropriate to modeling networks, an initial model, and discussion of alternative computer and communication technologies.

14. W. B. Rouse, J. L. Divilbiss, and S. H. Rouse, A Mathematical Model of the Illinois Interlibrary Loan Network: Project Report No. 2, Coordinated Science Laoratory Report No. T-16, University of Illinois at Urbana-Champaign, March 1975, ERIC No. ED 107 287.

Includes a derivation of the mathematical model (version no. 2) and its applications to a hypothetical network so as to illustrate various policy issues. A summary of the User's Manual for the interactive program of the model is also included.

15. W. B. Rouse, and S. H. Rouse, A Mathematical Model of the Illinois Interlibrary Loan Network: Project Report No. 3, Coordinated Science Laboratory Report No. T-26, University of Illinois at Urbana Champaign, April 1976, ERIC No. ED 124 179.

    Includes a detailed analysis of the Illinois network based on data obtained from the Illinois State Library and from the Library Research Center at the University of Illinois. Several alternative request routing policies are considered and specific recommendations are discussed.

16. W. B. Rouse and S. H. Rouse, A Mathematical Model of the Illinois Interlibrary Loan Network: Project Report No. 4, Coordinated Science Laboratory Report No. T-28, University of Illinois at Urbana-Champaign, June 1976, ERIC No. Ed 126 879. (See J. Am. Soc. for Info. Sci., Vol. 28, No. 2, 1977.)

    A procedure is developed for predicting the impact of computer technology on interliibrary loan activities. Specific examples include automated circulation systems and shared cataloging networks. The Illinois network is analyzed to determine the value of location and availability information as provided by the alternative computer technologies.

17. W. B. Rouse and S. H. Rouse, A Mathematical Model of the Illinois Interlibrary Loan Network: Project Report No. 5, Coordinated Science Laboratory Report T-31, University of Illinois at Urbana-Champaign, October 1976, ERIC No. ED 134 201. (see J. Am. Soc. for Info. Sci., Vol. 29, No. 4, 1978.)

    Estimation of model parameters is briefly discussed and a procedure for determining sample sizes and appropriate levels of data aggregation is presented. Results of applying the procedure within the Illinois network are discussed. In an appendix, a new derivation of the model is presented that requires fewer assumptions and allows more robust representations of library networks.

18. M. P. Slate, Application of a Library Network Model: A Case Study of the Rolling Prairie Library System, Report No. 6, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, January 1977, ERIC No. ED 140 797.

A detailed discussion of an application of the methodology developed in Report Nos. 2, 4, and 5 is presented. Problem definition, data collection, analyses, and recommendations are thoroughly considered.

19. S. H. Rouse and W. B. Rouse, Design of a Model-Based Online Management Information System for Interlibrary Loan Networks, Report No. 7, Coordinated Science Laboratory Report T-54, University of Illinois at Urbana-Champaign, December 1977, ERIC No. ED 160 054. (See Info. Proc. and Mgt., Vol. 15, No. 2, 1979.)

The design of a model-based online management information system is discussed in terms of mathematical/statistical, information processing, and human factors issues. Implementation of the prototype system for interlibrary loan networks is discussed and cost estimates for the particular applications are given.

20. W. B. Rouse and S. H. Rouse, Application of a Library Network Model: A Case Study of the Illinois Library and Information Network. Report No. 8, Coordinated Science Laboratory Report No. T-61, University of Illinois at Urbana-Champaign, February 1978, ERIC No. ED 163 931.

A case study of the Illinois Library and Information Network (ILLINET) was conducted by applying an analytical library network model to data which was collected during April 1977. Models are developed for describing the intralibrary processing activities encountered at each of the resource libraries in this case study. Alternative routing policies for referring requests among resource libraries are also analyzed. A recommended routing policy is suggested which predicts an improvement in network probability of satisfaction and a slight decrease in waiting time for roughly the same reimbursement cost experienced in April 1977.

21. S. H. Rouse, Application of a Library Network Model: A Case Study of the Suburban Library System, Report No. 9, Coordinated Science Laboratory Report No. T-74, University of Illinois at Urbana-Champaign, December 1978, ERIC No. not yet available.

A case study of the Suburban Library System (SLS) was conducted by applying an analytical library network model to data which was collected during March 1978. Models are developed for describing the intralibrary processing activities encountered at SLS and the other resource libraries in this case study. Alternative routing policies for referring requests among resource libraries are generated as a function of probability of satisfaction and waiting time. Constraints on the order of resource libraries in a referral route are also considered in generating alternative policies. Recommendations suggest specific changes in the reserve and purchase procedures at SLS which are predicted to improve overall network performance.

22. J. H. Kang, Approaches to Forecasting Demands for Library Network Services, Report No. 10, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, July 1979, ERIC No. not yet available.

The problem of forecasting monthly demands for library network services is considered, especially in terms of using forecasts as inputs to policy analysis models and, in terms of the use of forecasts as an aid to budgeting and staffing decisions. Forecasting methods considered include Box-Jenkins time series methodology, adaptive filtering, and linear regressions. Using demand data from the Illinois Library and Information Network for 1971-1978, it is shown that fading-memory regression is the most appropriate method, both in terms of accuracy and ease of use.